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TIME SERIES ANALYSIS AND FORECASTING OF BOILER EFFICIENCY

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ABSTRACT

Time series analysis is one of the techniques in statistics used for forecasting the data point or any parameter based on its previous history. Forecasting the parameter helps in accessing the market demand and the behavior of the entire system. In process industry, boiler is the most critical component, as it may explode if not taken care. Forecasting boiler efficiency helps in understanding the operational condition of boiler. If forecast suggests that the efficiency declines, then necessary actions for its improvements can be initiated immediately. Time series analysis is carried out in this paper to predict or forecast the boiler efficiency.

KEYWORDS: Forecast, Time Series Analysis, Boiler Efficiency

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Original Article

INTRODUCTION

Boiler is one of the important and commonly used components of process industry. Steam is generated from water using boilers. If the health of boiler is not taken care of, there is always a chance of boiler accidents. Essential goal of boiler operator is to meet performance and environmental safety with safe and trouble free operation. Boilers face several operating problems which may lead to causalities and material damage. Some of the problems are blockage in feed line, efficiency reduction/loss, material degradation, fouling. Broadly these operating problems can be classified as degradation of components and degradation of performance [1]. These industrial accidents are not restricted to developing countries like India or China, but common in all parts of the world.

According to statistics, 70 % of boiler accidents are due to water shortage in boilers [2]. 2710 boiler explosion accidents are reported within a span of 11 years (1976 to 1987) causing severe damage such as 1532 deaths and 5754 injuries, including damage to machinery [3]. Analysis reveals that the major boiler accidents are because of human's negative impact on machines and environment [4]. Even today, these accidents are continuing. Major industrial accident is reported in 2004 at Skikda, Algeria, due to over-heating of water leading to boiler explosion. 27 deaths and 74 injuries were reported with damage to plant [5],[6]. In Jae Shin conducted a statistical survey on major industrial accidents in Korea from 1996 to 2011 [7]. In this survey 147 cases are analyzed and 50 % of accidents are explosions [7].

These industrial accidents related to boiler can be minimized or eliminated if the operating condition of the boiler is known to the operator well in advance. Forecasting the condition of boiler is necessary to avoid boiler accidents. In this paper, the time series analysis of the boiler is carried out with the data collected by an industry.

This data is also utilized for forecasting the boiler efficiency. Boiler efficiency is one of the major metrics to understand the operating condition of the boiler.

Time Series Analysis

The series of data points measured at uniform time interval (daily, weekly, monthly, quarterly, half yearly or yearly) is called time series. When this time series data is analyzed, a meaningful statistics and important characteristics are extracted. Forecasting of the data is possible with time series analysis. Time series analysis leads to the development of a statistical model, which in turn helps to predict future values of the data points. The major components of time series are trend, cyclic variation, seasonal variation and irregular variation [8].

- **Trend**

When the data points are available, a trend is plotted to know the nature of data points over the period. The data points follow different patterns. The pattern may be linear, non-linear, exponential or quadratic. The pattern of the data points may steadily move upward, downward or stay constant over the period and is called the trend.

- **Cyclic variation**

Cyclic variation is the wave like or quasi regular fluctuations around (above and below) the trend line which lasts for more than a year.

- **Seasonal variation**

The repetitive and predictable fluctuation or movement around trend line within a period of one year or less than a year is termed as seasonal variation. The change which repeats based on the season is called seasonal variation. These fluctuations or patterns repeat themselves over a period of time.

- **Irregular or Random variation**

It is the deviation of the observed time series from the underlying pattern. There are two basic types of irregular variations- episodic variation and residual variation. Episodic variations are unpredictable and can be identified. Residual fluctuations are unpredictable and cannot be identified [9].

The four components of time series can be modeled in two ways - Additive and Multiplicative.

In Additive model, the time series model is represented as in equation (1).

$$Y_t = T_t + C_t + S_t + R_t \tag{1}$$

Where Y_t is the observed data, T_t is the trend component, C_t is the cyclic component, S_t is the seasonal component and R_t is the random component. Equation for observed data can be rewritten as

$$Y_t = (a + b \times t) + C_t + S_t + R_t \tag{2}$$

Where a is intercept of the trend line, b is the slope of the trend line, and t is the time period.

In Multiplicative model, the statistical model is represented in the following equation.

$$Y_t = T_t \times C_t \times S_t \times R_t \tag{3}$$

Or

$$Y_t = (a + b \times t) \times C_t \times S_t \times R_t \qquad 4$$

The multiplicative model is more popular, among the two time series models. Each model has both advantages and disadvantages. The fluctuations around the trend are of same intensity in additive model and are more intensive in multiplicative model.

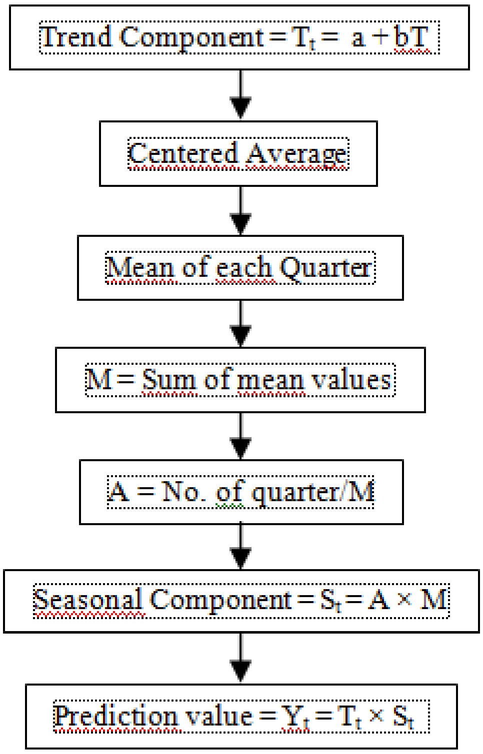

Figure 1: Flow of Prediction Process

The flow of multiplicative model in prediction process is explained in Figure 1. The trend component and the seasonal component are separately computed. Then the product of these two components is termed as prediction value of the parameter of interest. To compute seasonal component, calculation of sum of mean value for each quarter and the ratio of no of quarter and sum of mean value is essential. Cyclic and random components are ignored as the boiler efficiency value for each quarter is almost constant.

If the data points are fairly stable and have no significant trend, seasonal, or cyclic effects, the smoothing methods are available to average the irregular component of the time series data points. Following are the common smoothing methods:

- Moving averages
- Weighted Moving Averages
- Exponential Smoothing
- Centered Moving Average

In moving averages method, the arithmetic average of recent *n* data points is computed and this average is used for forecasting the value for the next period. Moving averages method is useful when the data point to be forecasted is steady over a period of time [10], [11].

In weighted moving average method, more weights are provided to most recent data points and less to old data points. These weights are considered according to intuition. They lie between 0 and 1 and add up to 1.

In exponential smoothing, there are three types: single exponential smoothing, double (Holt’s) exponential smoothing and triple (Winter’s) exponential smoothing.

In centered moving average method, an arithmetic average of previous *n* period data point and its mid-point of the period are evaluated. This method is very much useful in computing the seasonal index process.

Prediction of Boiler Efficiency Based on Time Series Analysis

The recorded data for three years from one of the leading cement industries is considered for time series analysis. The boiler efficiency for three years (2012 to 2014) is taken as the parameter for forecasting, as it is one of the major metric to understand the operational condition of the boiler. Table 1 shows the average boiler efficiency value for every two months in three years.

Data for every two months is considered as one quarter. Such six quarters are considered in one year. Each quarter may be of three months, two months or even every month. If one quarter is of three months, four quarters are considered in a year.

Table 1: Boiler Efficiency for Three Years

Year	Quarter	Boiler Efficiency (%)
2012	1	83.592
	2	82.908
	3	80.771
	4	80.040
	5	81.234
	6	82.411
2013	1	86.514
	2	80.527
	3	82.720
	4	80.823
	5	81.851
	6	85.295
2014	1	85.353
	2	86.347
	3	87.367
	4	82.279
	5	81.783
	6	85.295

Centered moving average method is one of the common techniques used for calculation of various components of time series analysis. The arithmetic average of four consecutive quarters is listed in Table 2 as 4QMA. The average of two consecutive 4QMA is listed as centered average and the ratio of original boiler efficiency to centered average is computed and that value is considered as average value of the boiler efficiency.

Table 3 shows the average value of boiler efficiency for every quarter and the mean values for each quarter to compute seasonal index, which is one of the components of time series analysis. Mean value is computed by considering two values for Q_1, Q_2, Q_4, Q_5 and Q_6, three values for Q_3. The summation of all mean values is computed and it is 600.193. As there are six quarters in a year, the ratio of 600 to summation of mean value is computed. This ratio is 0.999678 and it is used for computing the seasonal index for each quarter as the product of mean value of each quarter and this ratio.

Table 2: Boiler Efficiency Value and Its Average Value

Quarter	Y(BE)	4QMA	Centred Average	Average
1	83.592			
2	82.908			
		81.82763		
3	80.771		81.53288	99.06556
		81.23813		
4	80.040		81.17606	98.6005
		81.1140		
5	81.234		81.83188	99.26939
		82.5498		
6	82.411		82.61063	99.75835
		82.6715		
7	86.514		82.85725	104.4133
		83.0430		
8	80.527		82.8445	97.20259
		82.6460		
9	82.720		82.06306	100.8005
		81.4801		
10	80.823		82.07606	98.47329
		82.6720		
11	81.851		83.00106	98.6138
		83.3301		
12	85.295		84.02056	101.5162
		84.7110		
13	85.353		85.40056	99.94372
		86.0901		
14	86.347		85.71319	100.7389
		85.3363		
15	87.367		84.89006	102.9178
		84.4439		
16	82.279			
		84.1809		
17	81.783			
18	85.295			

Along with seasonal component, trend component is also necessary to forecast the boiler efficiency value. The trend component is computed by plotting the value of boiler efficiency for various quarters and is shown in Fig. 2. The trend line is also inserted. Linear regression model is suitable for the trend as it is having maximum coefficient for determination (R^2 value). The equation for the model is as in the following equation.

$$Y = 0.18 \times X + 81.45 \qquad 5$$

Where Y is the parameter to be forecasted (boiler efficiency), X is the number of quarter for which the boiler efficiency is to be forecasted. The value of the boiler efficiency is forecasted using both trend component and seasonal

component. In Table IV, Y_{19} to Y_{24} represent the four quarters for the year 2015. The forecasting of boiler efficiency is computed initially using equation for parameter to be forecasted, by substituting value of *X* as 19 for first quarter of the year 2015.

Table 3: Seasonal Index for Various Quarters

YEAR	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
2012			99.07	98.60	99.27	99.76
2013	104.41	97.20	100.81	98.47	98.61	101.52
2014	99.944	100.74	102.92			
MEAN	102.18	98.98	100.93	98.54	98.94	100.64
SEASONAL INDEX	102.15	98.94	100.90	98.51	98.91	100.61

The next column in Table 4 indicates FORECAST column, which is computed by multiplying the seasonal component along with the trend component. Then the fore casted value of boiler efficiency is compared with the actual value of boiler efficiency. Percentage of error is also calculated as the difference between forecasted value of boiler efficiency and its actual value.

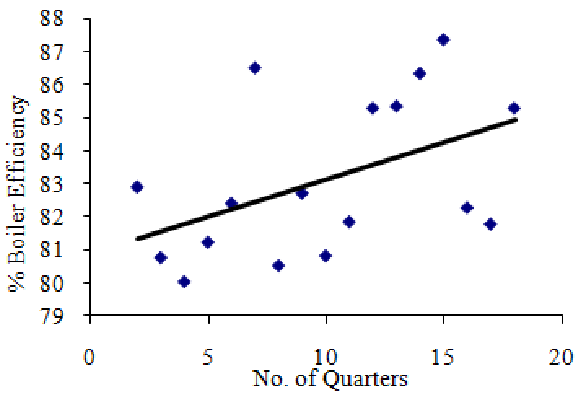

Figure 2: Trend Line for Boiler Efficiency for Various Quarters

Table 4: Forecasted and Actual Values of Boiler Efficiency

Y= 0.18 × X+81.45		FORCAST	ACTUAL	% ERROR
Y_{19}	84.87	87.23363	86.9315	-0.34755
Y_{20}	85.05	84.14677	83.9421	-0.24382
Y_{21}	85.23	85.99281	85.5249	-0.54710
Y_{22}	85.41	84.13312	84.2190	0.101972
Y_{23}	85.59	84.65621	84.8040	0.174272
Y_{24}	85.77	86.28805		

CONCLUSIONS

This paper focuses on the time series analysis on boiler efficiency. The forecasted boiler efficiency value is almost same as that of the actual value. The centered moving average method is used as the boiler efficiency is almost constant. The maximum percentage error in forecasting is 0.5471, which is a small quantity and can be neglected. Forecasting of boiler efficiency helps the personnel to understand the future condition of the boiler and the action can be initiated immediately to overcome the worst situation if any. The time series analysis method is usually performed on economical data. An effort is made in this paper to apply the centered moving average model to predict boiler efficiency.

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